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ORIGINAL ARTICLE

Ultrasound as a new tool in the assessment of airway difficulties

An observational study

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BACKGROUND Prediction of difficult mask ventilation (DMV) is as challenging as difficult laryngoscopy. Ultrasound could be a helpful tool in the prediction of these difficulties.

OBJECTIVES The purpose of this study was to evaluate the ability of pre-operative ultrasound assessment of neck anatomy in predicting DMV and difficult laryngoscopy in patients undergoing during elective surgery requiring tracheal intubation.

DESIGN Prospective, single blind, observational study.

SETTING Operating theatre of a teaching hospital in Italy from April 2018 to July 2018.

PATIENTS A total of 194 patients aged more than 18 years, without neck masses, previous thyroid surgery or tracheotomy undergoing general anaesthesia and tracheal intubation for elective ear, nose and throat-surgery were included in the study.

OUTCOME MEASURES Ultrasound distances were recorded with a linear 6 to 13 MHz ultrasound transducer: measurements included the minimum distance from the thyroid isthmus to skin surface, the minimum distance from the hyoid bone to skin surface (DSHB), the minimum distance from skin to anterior commissure of the vocal cords, the minimum distance from skin to trachea at the level of the jugular notch and the distance from skin to epiglottis midway. The degree of DMV and difficult laryngoscopy was quantified.

RESULTS The mean (SD) of DSHB was 0.88 (0.3) cm in the easy mask ventilation group, 1.4 (0.19) cm in DMV group. The mean of DSHB and of the other ultrasound distances increased according to the DMV and difficult laryngoscopy level. The DSHB was correlated with an increase in the risk for DMV (0.61 [IQR 0.5 to 0.69]). DMV groups were associated with a greater ultrasound-measured DSHB.

CONCLUSION The prospective observational study confirms the relationship between ultrasound assessment of the anterior soft tissues of the neck and difficult laryngoscopy and DMV. DSHB and the other distances extend the available evidence, not only for difficult laryngoscopy but also for DMV.

TRIAL REGISTRATION Clinicaltrials.gov. identified NCT03592758.

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Introduction

In both the elective and emergency settings there is a potential for tracheal intubation to fail, and a consequential failure to provide adequate oxygenation and CO_2 removal can lead to life-threatening complications.[1,2] Available guidelines provide indices to predict the risk of difficult laryngoscopy but, despite these, unpredicted difficult laryngoscopy complicates 1.5 to 13% of cases.[3] Safe management of the airway before tracheal intubation or after failed intubation (i.e. effective mask ventilation) plays a critical role that is sometimes overlooked.[4] Despite similarities in predictors, the incidence of difficult mask ventilation (DMV) is distinct from difficult laryngoscopy.[5–11] Patients presenting with difficult laryngoscopy associated with DMV, especially if these are unpredicted, represent the highest risk subgroup.

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Diagnostic tools that help in predicting patients who are likely to have DMV can contribute to safer airway management and must be considered as an adjunct to the conventional pre-operative clinical assessment. During the last few years ultrasound has been widely used in the operating room for ultrasound-guided procedures such as nerve block or central venous access. Ultrasound provides quick, relatively easy, and accurate information, with diagnostic and therapeutic relevance.[12,13] For some considerable time ultrasound has not been taken into consideration as a tool for the evaluation of the airway or as a predictor of difficult laryngoscopy.[14–19] Pre-operative ultrasound measurement of the anterior neck soft-tissue thickness at different levels, combined with the commonly used screening tests and risk factor assessment for difficult laryngoscopy might improve the ability to predict difficult laryngoscopy. Research regarding DMV combined with difficult laryngoscopy is extremely limited even though these two aspects of airway management are closely related.[20]

The aim of this study was to evaluate the accuracy of pre-operative ultrasound assessment of neck anatomy in predicting DMV and difficult laryngoscopy, in mostly ENT (ear, nose and throat) patients undergoing elective tracheal intubation for general anaesthesia.

Methods

The study was approved by the Ethical Committee of Azienda Policlinico Umberto I 'Sapienza' University of Rome (Rome, Italy) (Protocol No. 2017-4498) on 30 March 2017, Chairperson Prof. G. Spera. All study participants gave informed written consent and the research was conducted in accordance with the Helsinki Declaration. From April 2018 to July 2018, in Policlinico Umberto I (Rome, Italy), a nonselected series of consecutive patients aged more than 18 years undergoing general anaesthesia for elective ENT-surgery, were prospectively enrolled. Exclusion criteria were any of the following: facial, cervical, pharyngeal and epiglottic cancer or trauma, previous thyroid surgery or tracheotomy, pregnancy. The data collection form included a standard airway physical examination (ASA-PS) and the type of surgery. Data were recorded by two different anaesthetists: one measured ultrasound distances, the other, blinded to ultrasound distances, was in charge of the clinical aspects of the case, undertaking mask ventilation and intubation as well as grading the difficulty of laryngoscopy and mask ventilation.

On arrival in the pre-operative room, with the patient lying supine with the head and neck in a neutral position, the thicknesses of the anterior neck soft tissues were measured with a portable ultrasound machine (SonoSite NanoMaxx; SonoSite, Bothell, Washington, USA) with a linear 6 to 13 MHz ultrasound transducer. After a craniocaudal sagittal scan of the neck with the probe placed in the transverse axis, ultrasound distances were measured: the minimum distance from the thyroid isthmus to skin surface (DSTI); the minimum distance from the hyoid bone to skin surface (DSHB); the minimum distance from skin to anterior commissure of the vocal cords (DSAC); the minimum distance from skin to the trachea at the level of the jugular notch (DSTJ); and at the thyrohyoid membrane level, with the probe placed on sagittal axis, the minimum distance from the skin to the point of the epiglottis corresponding to half the distance between the hyoid bone and the thyroid cartilage (DSEM)[18] (Fig. 1).

Anaesthesia was induced with propofol 2 to 2.5 mg kg^{-1}, fentanyl 2 to 4 μg kg^{-1}, and cisatracurium 0.15 mg kg^{-1} and mask ventilation was performed using a clear disposable plastic mask. The grade of DMV was evaluated using the four level Han scale: first, ventilated by mask; second, ventilated by mask with oral airway/adjuvant, with or without muscle relaxant; third, difficult ventilation (inadequate, unstable or requiring two providers), with or without muscle relaxant; fourth, unable to mask ventilate, with or without muscle relaxant.[20,21] After adequate relaxation had been achieved, tracheal intubation was attempted by direct laryngoscopy using an appropriately sized Macintosh blade. Tracheal intubation was performed by an experienced anaesthetist (>5 years of clinical practice) blinded to the results of the ultrasound assessment. The laryngoscopic view was graded according to the Cormack–Lehane scale.[22] Difficult laryngoscopy was considered difficult if the Cormack–Lehane grade was at least 2B and DMV if the Han scale was at least III. The primary endpoint of this study was to evaluate if DSHB can be predictive of DMV. Secondary endpoints were the relationship between DSTI, DSEM, DSAC, DSTJ and DMV. We also investigated the relationship between ultrasound-recorded measures and Cormack–Lehane scale.

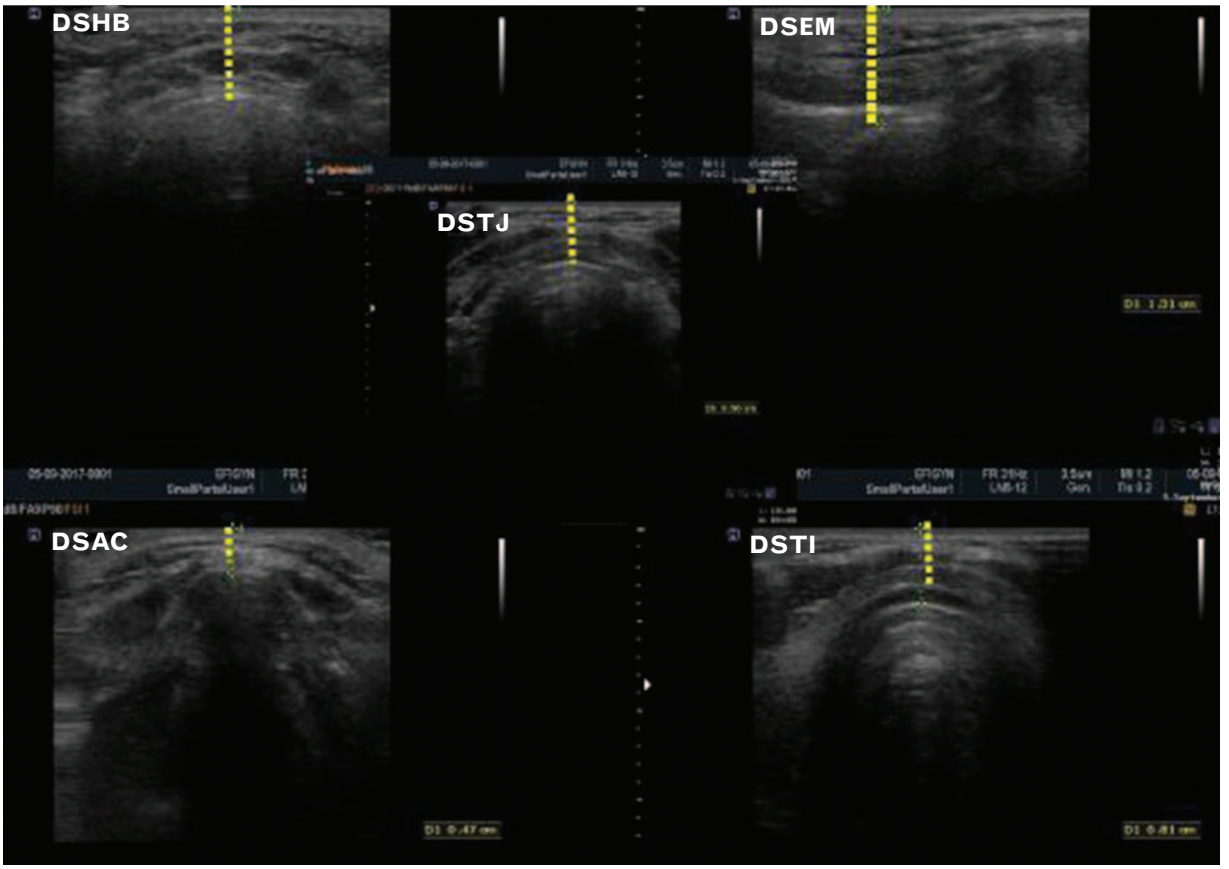
Statistical analysis

Based on the primary endpoint and assuming a correlation of 0.2, we expected the inclusion of 194 patients to guarantee a power of 80%, with a level of significance of 5%. Continuous data were expressed as mean (SD), whereas categorical data were expressed as frequencies (%). Pearson correlation coefficients were calculated to evaluate the dependence between the variables. Receiver-operating characteristic curves (ROC) were used to determine the sensitivity and specificity of the measured ultrasound distances.

Results

A total of 194 eligible patients (76 female, 118 male) were included in this study. Their personal and clinical characteristics are summarised in Table 1. In our study population, 135 (69.6%) patients presented with a DMV-I, 51 (26.3%) patients DMV-II and eight (4.1%) patients DMV-III. No patient had a DMV-IV; 91 (47%)

Fig. 1



Ultrasound distances: DSHB, distance from skin to the hyoid bone; DSEM, distance from skin to epiglottis midway; DSTJ, distance from skin to trachea at jugular notch; DSAC, distance from skin to anterior commissure of the vocal cords; DSTI, distance from skin to thyroid isthmus.

patients had a Cormack–Lehane 1, 69 (36%) 2A, 21 (11%) 2B, 10 (5%) 3A and three (1%) 3B. No patient had a Cormack–Lehane 4.

Table 2 shows the summary statistics of the ultrasound distances graded for DMV and difficult laryngoscopy. Mask ventilation was difficult in eight patients and easy in 186, while direct laryngoscopy was difficult in 34 patients and easy in 160. Ultrasound measures (DSTI, DSHB, DSEM, DSTJ, DSAC), were positively correlated (Fig. 2). However, the DSHB seemed better correlated with both DMV and difficult laryngoscopy than the other ultrasound measures: The median [IQR] Pearson correlation coefficient was 0.61 [0.5 to 0.69] for DMV and 0.34 [0.21 to 0.46] for difficult laryngoscopy: the greater the distance the higher the DMV grade (Table 3).

In Fig. 3, the correlation between ultrasound distances and Han scale grade for mask ventilation is shown by comparison of the area under the ROC curves The best predictor of DMV (Han scale >3) was the DSHB [Area Under the Curve (AUC) 0.93; 95% confidence interval 0.87 to 0.93)] (Fig. 3).

Discussion

Data analysis from this prospective observational study in 194 patients, confirms and extends available evidence on the relationship between ultrasound assessment of the anterior neck soft tissues and difficult laryngoscopy and DMV. DSHB was a better predictor of DMV than other distance measurements.

Available evidence reports mixed results on the value of ultrasound neck screening to predict difficult laryngoscopy.[3,6,18,23] In one study, the relationship between ultrasound-measured anterior neck soft-tissue thickness at the hyoid bone and thyrohyoid membrane levels predicted difficult laryngoscopy but there was no relationship between the ultrasound measurements and clinical screening tests.[3] A similar study showed that both ultrasound quantification of anterior neck soft tissues and general bedside screening tests failed to predict difficult laryngoscopy in obese patients.[6] In another study of obese patients, an ultrasound-detected abundance of fat tissue at the anterior neck region was an independent

Table 1 Patient demographics and pre-operative variables

Age (years)	47.6 (16.4)
Sex	
M	118 (60.8%)
F	76 (39.2%)
Height (cm)	169.6 (8.9)
Weight (kg)	73.7 (15.7)
BMI (kg m^{-2})	25.5 (3.9)
ASA physical status	
1	80 (41.3%)
2	99 (51%)
3	15 (7.7%)
4	0 (0.0%)
Mallampati score	
1	90 (46.3%)
2	82 (42.2%)
3	21 (10.8%)
4	(0.5%)
Thyromental distance	
>6 cm	187 (96.4%)
<6 cm	7 (3.6%)
Mouth opening interincisor distance	
>3 cm	194 (100%)
<3 cm	0 (0%)
Neck circumference	38.5 (4.0)
Mandibular protusion test	
Normal	190 (98%)
Limited	4 (2%)
Full beard	
Y	20 (11.5%)
N	174 (88.5%)
Dentition	
Normal	172 (88.7%)
Dentures upper	6 (3%)
Dentures lower partial	2 (1%)
Teeth missing/loose/broken	0 (0%)
Edentulous	14 (7.3%)
History of snoring occurring nightly	
Y	80 (41.3%)
N	114 (58.7%)
History of OSAS requiring CPAP	
Y	17 (8.8%)
N	177 (91.2%)
Surgery	
Fess	57 (29.3%)
TPL	39 (20.1%)
MLS	42 (21.6%)
SPL	28 (14.4%)
Other	28 (14.4%)

Numerical data are expressed as mean (SD) and number (%); CPAP, Continous Positive Airway Pressure; Fess, functional endoscopic sinus surgery; MLS, microlaryngoscopy; OSAS, Obstructive Sleep Apnea Syndrome; SPT, septoplasty; TPL, tympanoplasty.

predictor of difficult laryngoscopy and was more specific than the BMI.[23] The sensitivity of ultrasound in predicting difficult laryngoscopy is proven by the strong positive linear correlation among the thicknesses of anterior neck soft tissue measured by ultrasound at the hyoid bone, thyrohyoid membrane, and anterior commissure levels.[18]

To date no evidence is available on ultrasound measurement of the anterior soft tissues of the neck and DMV. Although the Han scale is neither objective nor validated, it is the most commonly used method for grading DMV. We investigated five different distances by adding DSTI and DSTJ to the three measures proposed by Wu *et al.*,[18] and investigated their relationship with DMV. Our data are in agreement with previous evidence in that there is was a statistically positive association between the increased thickness of the anterior neck soft tissues at all five levels and not only the incidence of difficult laryngoscopy, but also the incidence of DMV. This is especially so for DSHB which showed a higher correlation. Results of the comparison of the five distances are consistent.

The study was performed in ENT patients and airway management is often difficult in this population. Thus, this choice of patient should allow us to study the ultrasound measurements as independent predictive assessments of a difficult airway, and to identify difficult laryngoscopy and DMV in patients with no clinically predictable difficulty. Patients with abnormal airways were excluded as our intention was to provide an additional tool to increase the detection of unpredicted DMV and difficult laryngoscopy.

DSHB is perhaps the more stable distance. In a study by Adhikari *et al.*[15] DSEM and DSHB were evaluated and both were considered predictive of difficult airway management. However, DSEM is too dependent on the length of the epiglottis. In the study of Wu *et al.*,[18] DSHB had a higher specificity and sensitivity in detecting difficult laryngoscopy, possibly because the hyoid is the fulcrum of the upper airway: it is connected to the tongue by genioglossus muscle and to the larynx through the hyoepiglottic and thyrohyoid membranes and thus can affect every aspect of airway management.

Table 2 Ultrasound distances graded for DMV and DL

		DMV Han Scale		DL Modified Cormack–Lehane Scale	
	Total, $n = 194$	Easy, $n = 186$	Difficult, $n = 8$	Easy, $n = 160$	Difficult, $n = 34$
DSHB	0.90 (0.31)	0.88 (0.30)	1.40 (0.19)	0.86 (0.28)	1.08 (0.41)
DSTI	0.79 (0.26)	0.78 (0.25)	1.08 (0.33)	0.78 (0.24)	0.86 (0.31)
DSEM	0.80 (0.24)	0.79 (0.23)	0.99 (0.32)	0.78 (0.22)	0.91 (0.28)
DSTJ	1.14 (0.39)	1.13 (0.39)	1.51 (0.30)	1.12 (0.39)	1.24 (0.37)
DSAC	0.76 (0.17)	0.76 (0.17)	0.83 (0.17)	0.75 (0.16)	0.81 (0.20)

Numerical data are expressed as mean (SD) centimetres. DL, difficult laryngoscopy; DMV, difficult mask ventilation; DSAC, distance from skin to anterior commissure of the vocal cords; DSEM, distance from skin to epiglottis midway; DSHB, distance from the hyoid bone to skin surface; DSTI, distance from the thyroid isthmus to skin surface; DSTJ, distance from skin to trachea at jugular notch.

Fig. 2

Scatter Plot and Pearson's Correlation Coefficient Matrix for comparisons among the five ultrasound measurements. The five ultrasound measurements are labelled diagonally from top left to bottom right. The intersections of the rows and columns above the diagonal show the Pearson's correlation coefficients (*r*) with their *P* values. The intersections of the rows and columns below the diagonal illustrates their respective scatter plots. All ultrasound distances are expressed in centimetres. DSAC, distance from skin to anterior commissure of the vocal cords; DSEM, the distance from the skin to the point of the epiglottis corresponding to half the distance between the hyoid bone and the thyroid cartilage; DSHB, distance from skin to the hyoid bone; DSTI, distance from skin to thyroid isthmus; DSTJ, distance from skin to trachea at jugular notch.

The study is a first attempt to find new ultrasound parameters to improve the specificity and sensitivity of anthropometric parameters for the pre-operative evaluation of the upper airway. Computed tomography, MRI and other imaging techniques can measure the thickness of the soft tissues of the neck, but are expensive and not available in the operation room. Ultrasound is bedside, radiation-free, cheap, fast and as accurate as MRI.[24,25]

Table 3 Pearson correlation indices (95% confidence interval) between ultrasound distances and the grade scales difficult mask ventilation and difficult laryngoscopy

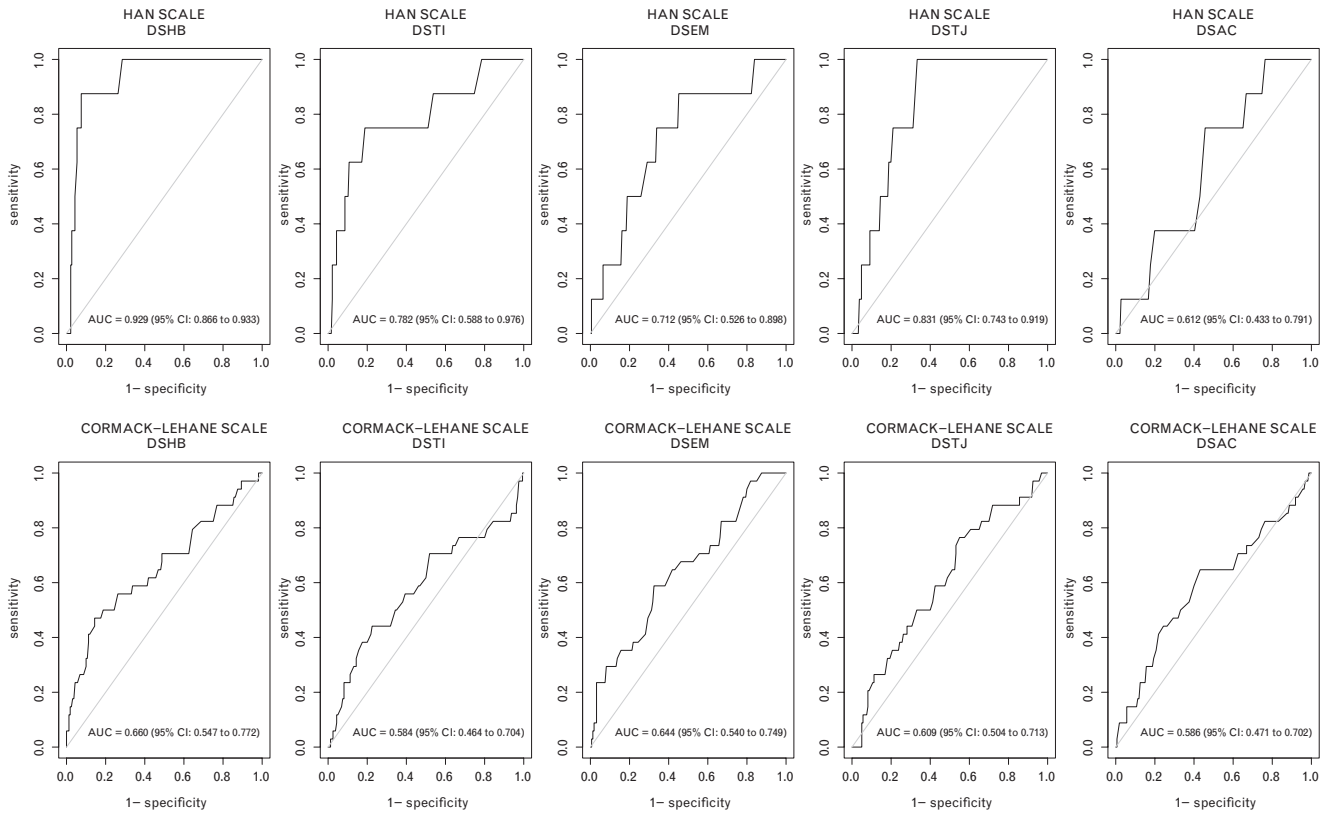
	DMV	DL
DSHB	0.608 (0.512 to 0.690)	0.345 (0.215 to 0.463)
DSTI	0.406 (0.280 to 0.517)	0.301 (0.168 to 0.424)
DSEM	0.488 (0.372 to 0.588)	0.273 (0.138 to 0.399)
DSTJ	0.359 (0.230 to 0.476)	0.210 (0.072 to 0.341)
DSAC	0.289 (0.155 to 0.413)	0.144 (0.003 to 0.279)

DL, difficult laryngoscopy; DMV, difficult mask ventilation; DSAC, distance from skin to anterior commissure of the vocal cords; DSEM, distance from skin to epiglottis midway; DSHB, distance from the hyoid bone to skin surface; DSTI, distance from the thyroid isthmus to skin surface; DSTJ, distance from skin to trachea at jugular notch.

There are several limitations in our study. First, we have not defined a cut-off value for the DSHB that is useful to quantify DMV or difficult laryngoscopy. Another aspect for further study is the comparison between ultrasound distances and anthropometric parameters currently considered as a reference: in particularly it would be very interesting to evaluate the relationship with neck circumference, which is related to DMV.[26] Finally, it should be remembered that patients with predicted difficult airway management were excluded as the study aim was to investigate the use neck ultrasound in patients for whom the potential for DMV and difficult laryngoscopy was not predictable pre-operatively.

In summary, the growing interest in the use of ultrasound to assist airway management and the study of the anatomy of the anterior region of the neck as revealed by ultrasound, will be helpful in developing new predictors for DMV and difficult laryngoscopy. Longer distances from skin to larynx, appear predictive of both DMV and difficult laryngoscopy, and DSHB seems to be better than the other distances, however further studies are needed to identify the most accurate and easy parameter to predict difficult laryngoscopy and DMV.

Fig. 3



Receiver operating characteristic curve analyses of the five ultrasound measurements and Han Scale at least III (top row) and Cormack–Lehane at least 2B (bottom row). DSAC, distance from skin to anterior commissure of the vocal cords; DSEM, the distance from the skin to the point of the epiglottis corresponding to half the distance between the hyoid bone and the thyroid cartilage; DSHB, distance from skin to the hyoid bone; DSTI, distance from skin to thyroid isthmus; DSTJ, distance from skin to trachea at jugular notch.

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